PA NT COOPERATION TREAT

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 25 January 2001 (25.01.01)	
International application No. PCT/GB00/01903	**Applicant's or agent's file reference** RL.P50670PC
International filing date (day/month/year) 18 May 2000 (18.05.00)	**Priority date** (day/month/year) 09 June 1999 (09.06.99)
Applicant PAIN, Douglas et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

14 December 2000 (14.12.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer S. Mafla
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

BOWDERY, Anthony, Oliver
Intellectual Property Dept.
G016 A4 Building
DERA Farnborough
Ively Road
Hants GU14 0LX
ROYAUME-UNI

Date of mailing (day/month/year)
25 June 2001 (25.06.01)

Applicant's or agent's file reference
IPD65/N230

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/01903

International filing date (day/month/year)
18 May 2000 (18.05.00)

1. The following indications appeared on record concerning:

[ ] the applicant [ ] the inventor [X] the agent [ ] the common representative

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2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

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State of Residence:
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Teleprinter No.:

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

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Authorized officer
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PA[illegible]NT COOPERATION TREAT[illegible]

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

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ROYAUME-UNI

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Applicant's or agent's file reference
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IMPORTANT NOTIFICATION

International application No.
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International filing date (day/month/year)
18 May 2000 (18.05.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address

THE SECRETARY OF STATE FOR DEFENCE
IN HER BRITANNIC MAJESTY'S
GOVERNMENT OF THE UNITED KINGDOM
OF GREAT BRITAIN AND NORTHERN
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2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

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State of Residence: US
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3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
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Authorized officer
R. Chrem

Telephone No.: (41-22) 338.83.38

C py f r the Elected Office (EO/US)

PCT/GB00/01903

P NT COOPERATION TREAT

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

LIND, Robert
Marks & Clerk
4220 Nash Court
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ROYAUME-UNI

Date of mailing (day/month/year)
25 October 2001 (25.10.01)

Applicant's or agent's file reference
RLP50670PC

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/01903

International filing date (day/month/year)
18 May 2000 (18.05.00)

1. The following indications appeared on record concerning:

[ ] the applicant [ ] the inventor [X] the agent [ ] the common representative

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3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO
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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
RL.P50670PC		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/01903	18/05/2000	09/06/1999
International Patent Classification (IPC) or national classification and IPC		
G02B5/32		
Applicant		
THE SECRETARY OF STATE FOR DEFENCE ... et al		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
14/12/2000	19.06.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Thieme, W Telephone No. +49 89 2399 2597

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/01903

I. Basis f th rep rt

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1,5-10	as originally filed			
2-4,4a	as received on	02/06/2001	with letter of	29/05/2001

Claims, No.:

1-11	as received on	02/06/2001	with letter of	29/05/2001

Drawings, sheets:

1/6-6/6	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-11
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-11
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-11
	No:	Claims	

2. Citations and explanations
   see separate sheet

R It m V

Reasoned statement under Article 35(2) with regard to novelty, inventive step r industrial applicability; citations and explanations supporting such statement

1. Claim 1 is related to a holographic display in accordance with document US, 5 652 666, A. In such a display, an electrically addressable spatial light modulator 14 is arranged to display successively a set of sub-holograms which together form a holographic image. Light guiding means 41-44 guide the modulated light such that the sub-holograms appear in respective tiled regions of a projection surface 46.

2. The holographic display of claim 1 is distinguished from that of document US'666 by a source of coherent light arranged to illuminate the spatial light modulator with at an angle of incidence which depends on the spatial position of the a sub-hologram within the complete holographic image, whereas in the prior art document, positioning of the sub-holograms in corresponding tiles of the projection surface is achieved by means of a rotating mirror 45.

3. In document US, 5 172 251, A, a scanner 34 with a rotating mirror is used for multiplexing of sub-holograms.

   Document GB, 2 330 471, A, suggests two solutions for displaying a multiplexed hologram:
   * the spatial light modulator system is arranged to deflect modulated light to the corresponding positions in the tiled hologram, see claim 3 in connection with figure 4;
   * each of a plurality of spatial light modulators projects light onto a projection surface, see claim 4 and figure 2.

   Document US, 5 138 471, A relates to a different kind of holographic display; a plurality of minute holograms are stored on a medium by displacing the medium between the exposures.

   Hence, claim 1 appears to define a display system which is novel and non-obvious over the available prior art.

4. The above observation applies in a similar manner to method claim 9.

5. Independent claim 10 is also related to a holographic display in accordance with document US, 5 652 666, A.

   The holographic display of claim 10 is distinguished from that of document US'666 by an array of lenses disposed on the output side of the projection plane. The lenses correct for the apparent direction of illumination.

6. None of the display systems described in the prior art documents comprises an element with a corresponding effect.

as Active Tiling™, and involves the use of a relatively small EASLM 1 in combination with a relatively large Optically Addressable Spatial Light Modulator (OASLM) 2. The holographic matrix is subdivided into a set of sub-holograms, with the data for each sub-hologram being passed in turn to the EASLM 1. The EASLM 1 is illuminated from one side with incoherent light 3. The OASLM 2 comprises a sheet of bistable liquid crystal (in one example the liquid crystal is a ferroelectric liquid crystal) which is switched from a first to a second state by incident light. Guide optics 4, disposed between the EASLM 1 and the OASLM 2, cause the output of the EASLM 1 (i.e. light transmitted through the EASLM 1) to be stepped across the surface of the OASLM 2. The bistable nature of the OASLM liquid crystal means that the portion or "tile" 5 of the OASLM 2 onto which a sub-holographic image is projected, remembers that image until such time as the OASLM is reset by the application of an electrical voltage. It will be appreciated that, providing a reset voltage is applied only at the end of a complete scan, immediately prior to reset the OASLM 2 will have "stored" in it a replica of the complete holographic matrix. The holographic display also typically comprises a large output lens, although this is not shown in Figure 1.

The need for an OASLM 2 in the display of GB2330471A is demanding and expensive to implement in practice. Furthermore, the need for the OASLM to have memory and for it to be reset at the end of each scan, requiring as it does the use of surface electrodes, adds complexity and therefore yet more expense to the holographic display.

US5,652,666 describes apparatus for displaying holographic images. The apparatus comprises a spatial light modulator which generates images representing vertical strips of a hologram. A scanning mirror is used to scan the strips across an image plane such that a viewer perceives a composite hologram composed of these image strips.

It is an object of the present invention to overcome or at least mitigate the above noted disadvantages. This and other objects are achieved at least in part by providing a holographic display having an EASLM which is illuminated with coherent light and which is used to display sub-holographic images.

According to a first aspect of the present invention there is provided a holographic display comprising:

a source of coherent light;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to display successively a set of sub-holograms which together correspond to a holographic image; and

light guiding means arranged to guide modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface,

characterised in that

the source of coherent light is arranged to illuminate the EASLM with an angle of incidence which depends upon the spatial position within the hologram of a sub-hologram being displayed, the angle being switched in synchronisation with the sub-hologram update rate of the EASLM.

The present invention takes advantage of the "memory" which is inherent in the human eye. Providing that the light output corresponding to each sub-hologram is of sufficient amplitude, an observer will remember that sub-hologram at least for the time it takes to display the entire set of sub-holograms making up the sub-holographic image. There is thus no need for an OASLM.

In certain embodiments of the invention, the sub-hologram images appear at the projection surface as though they are illuminated with a plane wave

Preferably, said light guiding means comprises replicating optics arranged in use to replicate the light output from the EASLM so as to provide multiple images. More preferably, the light guiding means comprises an array of electronically controlled baffles or shutters disposed between the replicating optics and said EASLM projection surface, said baffles/shutters being controlled such that only that baffle/shutter, which is aligned with a tiled region of the EASLM projection surface associated with a given sub-hologram, is open when the EASLM is being driven by that sub-hologram.

Preferably, the light guiding means comprises means disposed at the EASLM projection surface, or between the EASLM and the EASLM projection surface, for causing diverging light to be redirected to provide a plane wave. More preferably, this means comprises an array of lenses or a holographic redirector disposed at or near the EASLM projection surface.

The sub-hologram images on the EASLM projection surface may produce discrete sets of wavefronts which converge on object points.

The light source used to illuminate the EASLM may comprise a single light source, or a plurality of light sources. For example, the light source may be an array of light sources disposed behind the replicating optics such that the EASLM is illuminated at the desired angle of incidence and with a wavefront of the desired form (e.g. plane/converging/diverging).

Preferably, the light source comprises an array of light sources disposed between a baffle/shutter array

According to a second aspect of the present invention there is provided a method of displaying a hologram, the method comprising:

successively displaying on an Electrically Addressable Spatial Light Modulator (EASLM) a set of sub-holograms which together correspond to a holographic image;

directing coherent light onto the EASLM; and

guiding modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

characterised by the steps of

illuminating the EASLM with said source of coherent light at an angle of incidence which depends upon the spatial position within the hologram of a sub-hologram being

displayed, and switching the angle in synchronisation with the sub-hologram update rate of the EASLM.

According to a third aspect of the present invention there is provided a holographic display comprising:

a light source;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to display successively a set of sub-holograms which together correspond to a holographic image;

light guiding means arranged to guide modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface; and

an array of lenses disposed on the output side of said EASLM projection plane, the lenses of the array being aligned with respective tiled regions.

For a better understanding of the present invention and in order to show how the same may be carried into effect reference will now be made, by way of example, the accompanying drawings, in which:

Claims

1. A holographic display comprising:

a source of coherent light;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to display successively a set of sub-holograms which together correspond to a holographic image; and

light guiding means arranged to guide modulated light output from the EASLM such that the sub-holograms appear successively in respective tiled regions of an EASLM projection surface.

characterised in that

the source of coherent light is arranged to illuminate the EASLM with an angle of incidence which depends upon the spatial position within the hologram of a sub-hologram being displayed, the angle being switched in synchronisation with the sub-hologram update rate of the EASLM.

2. A display according to claim 1, wherein said light guiding means comprises replicating optics arranged in use to replicate the light output from the EASLM so as to provide multiple images.

3. A display according to claim 2, wherein the light guiding means comprises an array of electronically controlled shutters disposed between the replicating optics and said EASLM projection surface, said shutters being controlled such that only that shutter, which is aligned with a tiled region of the EASLM projection surface associated with a given sub-hologram, is open when the EASLM is being driven by that sub-hologram.

4. A display according to any one of the preceding claims, wherein the light guiding means comprises means disposed at the EASLM projection surface, or between the EASLM and the EASLM projection surface, for causing the apparent diverging light illumination of the EASLM images to be redirected to appear to be a plane wave or other wavefront illumination.

5. A display according to claim 4, wherein said means causing diverging light to be redirected to provide an apparent wavefront illumination comprises an array of lenses or a holographic redirector disposed at or near the EASLM projection surface.

6. A display according to any one of the preceding claims, wherein the light source used to illuminate the EASLM comprises a single light source, or a plurality of light sources.

7. A display according to claim 6, wherein the light source comprises an array of light sources disposed behind the replicating optics.

8. A display according to any one of the preceding claims, wherein baffles are positioned in an intermediate image plane so that light associated with the d.c. spot and conjugate image is blocked.

9. A method of displaying a hologram, the method comprising:

successively displaying on an Electrically Addressable Spatial Light Modulator (EASLM) a set of sub-holograms which together correspond to a holographic image;

directing coherent light onto the EASLM; and

guiding modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface,

characterised by the steps of

illuminating the EASLM with said source of coherent light at an angle of incidence which depends upon the spatial position within the hologram of a sub-hologram being displayed, and switching the angle in synchronisation with the sub-hologram update rate of the EASLM.

10. A holographic display comprising:

a light source;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to display successively a set of sub-holograms which together correspond to a holographic image;

light guiding means arranged to guide modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface; and

an array of lenses disposed on the output side of said EASLM projection plane, the lenses of the array being aligned with respective tiled regions.

11. A holographic display comprising a plurality of displays according to claim 11, the displays being combined to enable a holographic image to be displayed with a large number of pixels.

displayed, and switching the angle in synchronisation with the sub-hologram update rate of the EASLM.

According to a third aspect of the present invention there is provided a holographic display comprising:

a light source;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to display successively a set of sub-holograms which together correspond to a holographic image;

light guiding means arranged to guide modulated light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface; and

an array of lenses disposed on the output side of said EASLM projection plane, the lenses of the array being aligned with respective tiled regions.

For a better understanding of the present invention and in order to show how the same may be carried into effect reference will now be made, by way of example, the accompanying drawings, in which:

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 December 2000 (14.12.2000)

PCT

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(30) Priority Data:
9913432.2 9 June 1999 (09.06.1999) GB

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(72) Inventors; and

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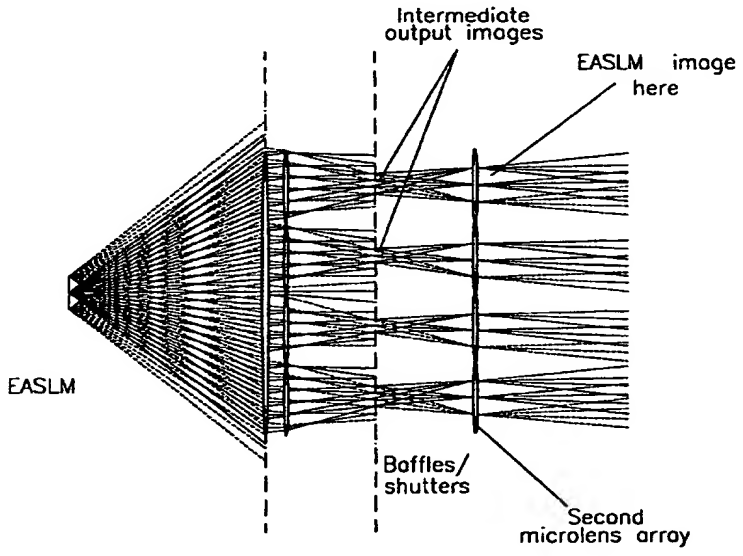
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: HOLOGRAPHIC DISPLAYS



(57) Abstract: A holographic display comprises a source of coherent light and an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source. The EASLM is arranged in use to be driven successively by a set of sub-holograms which together correspond to a holographic image. Light guiding means is arranged to guide light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

WO 00/75699 A1

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Holographic Displays

The present invention relates to holographic displays and in particular to holographic displays which use an electrically addressable spatial light modulator to generate modulated light for projection onto an optically addressable spatial light modulator.

It is well known that a three-dimensional image may be presented by forming an interference pattern or hologram on a planer surface. The three-dimensional image is visible when the hologram is appropriately illuminated. Recently, interest has grown in so-called computer generated holograms (CGHs) which offer the possibility of displaying high quality images, which need not be based upon real objects, with appropriate depth cues and without the need for viewing goggles. Interest is perhaps most intense in the medical and design fields where the need for realistic visualisation techniques is great.

Typically, a computer generated hologram involves the generation of a matrix of data values (each data value corresponding to a light transmission level) which simulates the hologram which, might otherwise be formed on a real planer surface. The matrix is applied to an Electrically Addressable Spatial Light Modulator (EASLM) which may be, for example, a two-dimensional array of liquid crystal elements or of acousto-optic modulators. Coherent light is directed onto the EASLM using for example a laser such that the resulting output, either reflected from the EASLM or transmitted through the EASLM, is a modulated light pattern.

In order to produce a three-dimensional image of usable size and viewing angle, the EASLM typically has to have a large number of pixels, e.g. 10^{10}. In addition, the pixels of the EASLM must be positioned relative to one another with a high degree of accuracy. The device must also be capable of modulating coherent light, e.g. produced by a laser. These requirements are extremely demanding and expensive to achieve in practice.

An alternative approach is presented in GB2330471A and is illustrated schematically in Figure 1. This document describes a holographic display technique, which is referred to

as Active Tiling™, and involves the use of a relatively small EASLM 1 in combination with a relatively large Optically Addressable Spatial Light Modulator (OASLM) 2. The holographic matrix is subdivided into a set of sub-holograms, with the data for each sub-hologram being passed in turn to the EASLM 1. The EASLM 1 is illuminated from one side with incoherent light 3. The OASLM 2 comprises a sheet of bistable liquid crystal (in one example the liquid crystal is a ferroelectric liquid crystal) which is switched from a first to a second state by incident light. Guide optics 4, disposed between the EASLM 1 and the OASLM 2, cause the output of the EASLM 1 (i.e. light transmitted through the EASLM 1) to be stepped across the surface of the OASLM 2. The bistable nature of the OASLM liquid crystal means that the portion or "tile" 5 of the OASLM 2 onto which a sub-holographic image is projected, remembers that image until such time as the OASLM is reset by the application of an electrical voltage. It will be appreciated that, providing a reset voltage is applied only at the end of a complete scan, immediately prior to reset the OASLM 2 will have "stored" in it a replica of the complete holographic matrix. The holographic display also typically comprises a large output lens, although this is not shown in Figure 1.

The need for an OASLM 2 in the display of GB2330471A is demanding and expensive to implement in practice. Furthermore, the need for the OASLM to have memory and for it to be reset at the end of each scan, requiring as it does the use of surface electrodes, adds complexity and therefore yet more expense to the holographic display.

It is an object of the present invention to overcome or at least mitigate the above noted disadvantages. This and other objects are achieved at least in part by providing a holographic display having an EASLM which is illuminated with coherent light and which is used to display sub-holographic images.

According to a first aspect of the present invention there is provided a holographic display comprising:

a source of coherent light;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to be driven successively by a set of sub-holograms which together correspond to a holographic image; and

light guiding means arranged to guide light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

The present invention takes advantage of the "memory" which is inherent in the human eye. Providing that the light output corresponding to each sub-hologram is of sufficient amplitude, an observer will remember that sub-hologram at least for the time it takes to display the entire set of sub-holograms making up the sub-holographic image. There is thus no need for an OASLM.

In certain embodiments of the invention, the sub-hologram images appear at the projection surface as though they are illuminated with a plane wave

Preferably, said light guiding means comprises replicating optics arranged in use to replicate the light output from the EASLM so as to provide multiple images. More preferably, the light guiding means comprises an array of electronically controlled baffles or shutters disposed between the replicating optics and said EASLM projection surface, said baffles/shutters being controlled such that only that baffle/shutter, which is aligned with a tiled region of the EASLM projection surface associated with a given sub-hologram, is open when the EASLM is being driven by that sub-hologram.

Preferably, the light guiding means comprises means disposed at the EASLM projection surface, or between the EASLM and the EASLM projection surface, for causing diverging light to be redirected to provide a plane wave. More preferably, this means comprises an array of lenses or a holographic redirector disposed at or near the EASLM projection surface.

The sub-hologram images on the EASLM projection surface may produce discrete sets of wavefronts which converge on object points.

The light source used to illuminate the EASLM may comprise a single light source, or a plurality of light sources. For example, the light source may be an array of light sources disposed behind the replicating optics such that the EASLM is illuminated at the desired

angle of incidence and with a wavefront of the desired form (e.g. plane/converging/diverging).

Preferably, the angle of incidence of the light upon the EASLM depends upon the spatial position, within the hologram, of a sub-hologram currently being displayed, the angle being switched in synchronisation with the sub-hologram update rate of the EASLM. More preferably, the light source comprises an array of light sources disposed between a baffle/shutter array

According to a second aspect of the present invention there is provided a method of displaying a hologram, the method comprising:

successively driving an Electrically Addressable Spatial Light Modulator (EASLM) with a set of sub-holograms which together correspond to a holographic image;

directing coherent light onto the EASLM; and

guiding light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

According to a third aspect of the present invention there is provided a holographic display comprising:

a light source;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to be driven successively by a set of sub-holograms which together correspond to a holographic image;

light guiding means arranged to guide light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface; and

an array of lenses disposed on the output side of said EASLM projection plane, the lenses of the array being aligned with respective tiled regions.

For a better understanding of the present invention and in order to show how the same may be carried into effect reference will now be made, by way of example, the accompanying drawings, in which:

Figure 1 illustrates an Active Tiling™ holographic display system;

Figure 2 illustrates EASLM images formed at an EASLM projection surface by illuminating the EASLM with coherent light;

Figure 3 illustrates EASLM images formed at an EASLM projection surface by illuminating the EASLM with coherent light but where light is redirected at the EASLM projection surface by a microlens array;

Figure 4 illustrates EASLM images formed at an EASLM projection surface by illuminating the EASLM with coherent light but where light is redirected at the EASLM projection surface by a holographic redirecting element;

Figure 5 illustrates schematically an EASLM illumination process;

Figure 6 illustrates schematically an alternative EASLM illumination process;

Figure 7 illustrates schematically a portion of an output section of a conventional holographic display; and

Figure 8 illustrates schematically a portion of an output section of an improved holographic display.

There is illustrated schematically in Figure 2 an Active Tiling™ holographic display which comprises an Electrically Addressable Spatial Light Modulator (EASLM) arranged to receive holographic image data from a computer (not shown). The EASLM may be for example an acousto-optic modulator which is sub-divided into a matrix of modulation elements or an array of liquid crystal elements.

The image data received from the computer comprises a series of sub-holograms or hogels (e.g. parts of a larger hologram, holographic stereograms, or phase added stereograms) each consisting of a matrix of light modulation data: when tiled together, these matrices provide a complete data array defining a hologram. The sub-hologram matrices are passed to the EASLM in a raster-scan like sequence, i.e. row by row. The sub-holographic matrices are mapped in turn to the EASLM modulation elements, with the data (or rather a corresponding voltage) at each matrix point being assigned to a corresponding modulation element. A beam of coherent light, provided as described below, is directed onto the surface of the EASLM. Light reflected from the EASLM is modulated by an amount determined by the voltage applied to the modulation element through which it passes.

Light reflected from the EASLM is directed towards a light guiding system. The light guiding system comprises a first large lens followed by an array of light directing lenses. Disposed in front of the lense array is an array of electronically controlled shutters. The shutter array is aligned with the lens array and is controlled by control signals received from the computer which generates the holographic image data. The control signals are synchronised with the image data provided by the computer to the EASLM, such that only one shutter is open at any one time. In addition, each shutter is open for approximately the duration for which a sub-hologram image is present on the EASLM. The shutters are opened in a raster scan sequence, from left to right and row by row.

Each lens of the lens array is arranged to guide light, transmitted through the shutter with which it is aligned, to a corresponding region (referred to as a "tile") of an EASLM projection surface (in this example, the virtual surface is a planar surface although it could be, for example, spherical or cylindrical). The result of the synchronisation between the switching of the EASLM between sub-holograms, and the opening of the shutters of the array, is that each sub-hologram is projected in turn onto the corresponding tile of the projection surface.

It is well known that the human eye and brain remember an image for a short time after that image has ceased to exist, providing that the intensity of the image is sufficiently great. The greater the intensity of the image, the longer the memory. The display device described here takes advantage of this perceptual memory by displaying a single tile of the projection surface for a time which is less than the total time which it takes to scan the entire hologram. That is to say that at any given time during the scanning process, only a fraction of the tiles may actually be presenting an image. At the end of a frame scan, the eye will perceive the complete image frame, even though only a fraction of the tiles making up that frame are actually displayed at any one time. The OASLM of the prior art (see Figure 1) becomes unnecessary.

From Figure 2 it will be appreciated that when the EASLM is illuminated with coherent light and images of coherently illuminated sub-holograms appear at the EASLM

projection surface (where the OASLM would have been). The disadvantage of using coherent light however is that greater care is needed over the direction of the illumination – although images of the EASLM appear in the correct positions, it is as though they are illuminated from the wrong angle.

This effect can be corrected by including additional optics in the system. Ray tracing shows that the necessary optic can be a second lens array placed at the projection plane of the EASLM images (Figure 3). Alternatively, a diffractive or holographic element can be used in place of the microlenses (Figure 4).

In order to ensure the correct functioning of the display, it is necessary that, for each sub-hologram, the EASLM 1 be illuminated by coherent light at the correct angle. This requires different angles for different sub-holograms. Noting that an intermediate image of the desired 3D object produced by each hogel occurs within the display, the following possibilities will be appreciated.

1) Light contributing to the d.c. spot and conjugate image in this plane can be blocked in the intermediate image plane. This minimises the amount of light passing through the remainder of the system, reducing glare. There is also a significant amount of free space for wires, connectors, etc associated with a shutter array.

2) By exploiting a symmetric lens array (or equivalent holographic redirector), locating a point source at the d.c. spot position for one lens should provide plane wave illumination of the EASLM at the correct angle for the image that passes through the opposite lens. The point source could be provided by a semiconductor laser or optical fibre/waveguide. This yields a potentially compact system.

3) By switching off light sources when they are not required, the amount of unwanted light passing through the system is reduced, again minimising glare. Shutters may still be required to eliminate the higher diffracted orders reflected from the EASLM if they aren't considered weak enough to be insignificant. This will largely depend on the structure of the EASLM pixels.

Figure 5 illustrates one suitable illumination system where an array of coherent light sources are provided in the plane of the shutter array. Figure 6 illustrates an alternative system which utilises an external plane wave although it is expected that this would be less efficient.

EASLM image magnification to provide the output display can be achieved by providing an output lens in front of the EASLM projection plane, the lens having an appropriate focal length. Replay optics downstream from the EASLM images can be the same as for a conventional system except that no provision need be made for providing 'OASLM read light illumination'. Alternatively, of course, the second lens array could be used to focus down an externally derived plane wave to give point sources although this would be a less desirable method (see Figure 6).

If the EASLM 1 is operated in transmission then illumination from the appropriate angles may be achieved by multiple sources or by some switchable optics. It may be beneficial to illuminate the EASLM with a non-plane wave although this is yet to be explored. For example, a converging wave may enable an EASLM with smaller pixels (larger diffraction angle) to be used whilst avoiding vignetting (light rays from regions on the EASLM 1 away from the centre not passing through the replicating optics). Converging wave illumination may be achieved simply by moving the point sources in a direction away from the EASLM.

It is noted that the embodiments described here are particularly suited to holograms composed of "hogels" (a type of sub-hologram). Hogels are described in the article "Holographic Bandwidth Compression Using Spatial Subsampling", M. Lucente, Optical Engineering, Vol. 35, No.6, June 1996. The use of hogels takes into account the finite resolution of the human eye to minimise the information content of the computer generated hologram (resulting in a lower resolution image). Hogels offer a method of computation which is potentially fast.

In essence, each hogel can be envisaged as diffracting beams of light into a number of directions. For each direction there is a corresponding fringe pattern that can be obtained from a look-up table. The brightness of beams in any direction (or indeed

whether there is a beam at all) is determined by whether the beam passes through a point on the 3D object and the brightness of the object at that point. The hogel to be displayed is the linear summation of all these fringe patterns, appropriately weighted to provide the required intensity in the image. The resolution of the image is approximately determined by the hogel size, so an attempt is made to match this size to the resolution of the viewer's eyes. This resolution matching is where minimisation of the computation time is expected to be achieved. Figure 2 illustrates the hogel 3D display principle.

One of the features of the hogel method is that, whilst each hogel needs to be illuminated with coherent light, the hogels can be incoherent with respect to each other. For the purpose of this discussion, the term discrete coherence (not to be confused with partial coherence) will be used to describe this. It is expected that such a discrete coherent display system would have reduced speckle in the image.

It is recognised here that a modified Active Tiling™ system could be particularly suited to provide discrete coherently illuminated hogels. The concept used is that the hogels are illuminated with coherent light, time sequentially, so that at any one time, the eye receives light from only one hogel. The 3D image is built up in the eye as it integrates the light contributions from all the hogels over time. This is an incoherent process. The tiling process of the Active Tiling™ system is, of course, time sequential. The speed of the time sequential illumination would need to be faster than the image latency of the eye (e.g. video frame rates).

It is expected that the hogel images do not need to be perfectly 'butted' together, relaxing optical design constraints. Deliberately overlapping hogels may allow some modification of the image quality (perhaps reducing the perception of hogel boundaries) although this would effectively require a greater number of pixels in the overall display.

The discrete coherent nature of the sub-holograms (and in particular of hogels) means that sub-hologram images can be tiled with individual optics, reducing the need for extra large elements. Figure 7 Schematic illustrates conventional replay optics where a single large lens (only the lower portion of the lens is shown in the Figure) is positioned

in front of the EASLM projection surface. Figure 8 illustrates how the use of tilted EASLM image 'planes' reduces the angle through which the replay optics have to direct the light. This allows the use of thinner, smaller optics.

It will be appreciated by the person of skill in the art that various modifications may be made to the above described embodiments without departing from the scope of the present invention. For example, the device described above may provide a single channel of a multi-channel holographic display. That is to say that a number of display devices may be arranged in an array such that the output provides a single hologram.

Claims

1. A holographic display comprising:

a source of coherent light;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to be driven successively by a set of sub-holograms which together correspond to a holographic image; and

light guiding means arranged to guide light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

2. A display according to claim 1, wherein said light guiding means comprises replicating optics arranged in use to replicate the light output from the EASLM so as to provide multiple images.

3. A display according to claim 2, wherein the light guiding means comprises an array of electronically controlled shutters disposed between the replicating optics and said EASLM projection surface, said shutters being controlled such that only that shutter, which is aligned with a tiled region of the EASLM projection surface associated with a given sub-hologram, is open when the EASLM is being driven by that sub-hologram.

4. A display according to any one of the preceding claims, wherein the light guiding means comprises means disposed at the EASLM projection surface, or between the EASLM and the EASLM projection surface, for causing the apparent diverging light illumination of the EASLM images to be redirected to appear to be a plane wave or other wavefront illumination.

5. A display according to claim 4, wherein said means causing diverging light to be redirected to provide an apparent wavefront illumination comprises an array of lenses or a holographic redirector disposed at or near the EASLM projection surface.

6. A display according to any one of the preceding claims, wherein the light source used to illuminate the EASLM may comprise a single light source, or a plurality of light sources.

7. A display according to claim 6, wherein the angle of incidence of the light upon the EASLM depends upon the spatial position, within the hologram, of a sub-hologram currently being displayed, the angle being switched in synchronisation with the sub-hologram update rate of the EASLM.

8. A display according to claim 6 or 7, wherein the light source comprises an array of light sources disposed behind the replicating optics.

9. A display according to any one of the preceding claims, wherein baffles are positioned in an intermediate image plane so that light associated with the d.c. spot and conjugate image is blocked.

10. A method of displaying a hologram, the method comprising:

successively driving an Electrically Addressable Spatial Light Modulator (EASLM) with a set of sub-holograms which together correspond to a holographic image;

directing coherent light onto the EASLM; and

guiding light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface.

11. A holographic display comprising:

a light source;

an Electrically Addressable Spatial Light Modulator (EASLM) in the path of the light source and arranged in use to be driven successively by a set of sub-holograms which together correspond to a holographic image;

light guiding means arranged to guide light output from the EASLM such that the sub-holograms are displayed successively in respective tiled regions of an EASLM projection surface; and

an array of lenses disposed on the output side of said EASLM projection plane, the lenses of the array being aligned with respective tiled regions.

12. A holographic display comprising a plurality of displays according to claim 11, the displays being combined to enable a holographic image to be displayed with a large number of pixels.

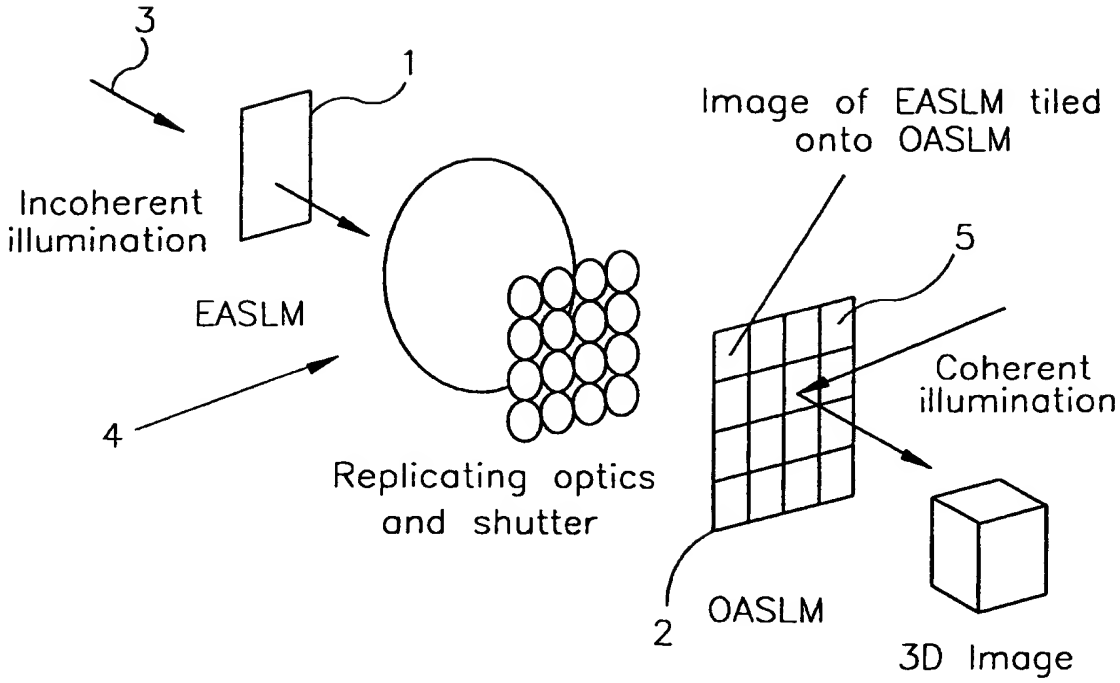

3
1
Incoherent
illumination
EASLM
4
Replicating optics
and shutter
Image of EASLM tiled
onto OASLM
5
Coherent
illumination
2
OASLM
3D Image

FIG 1

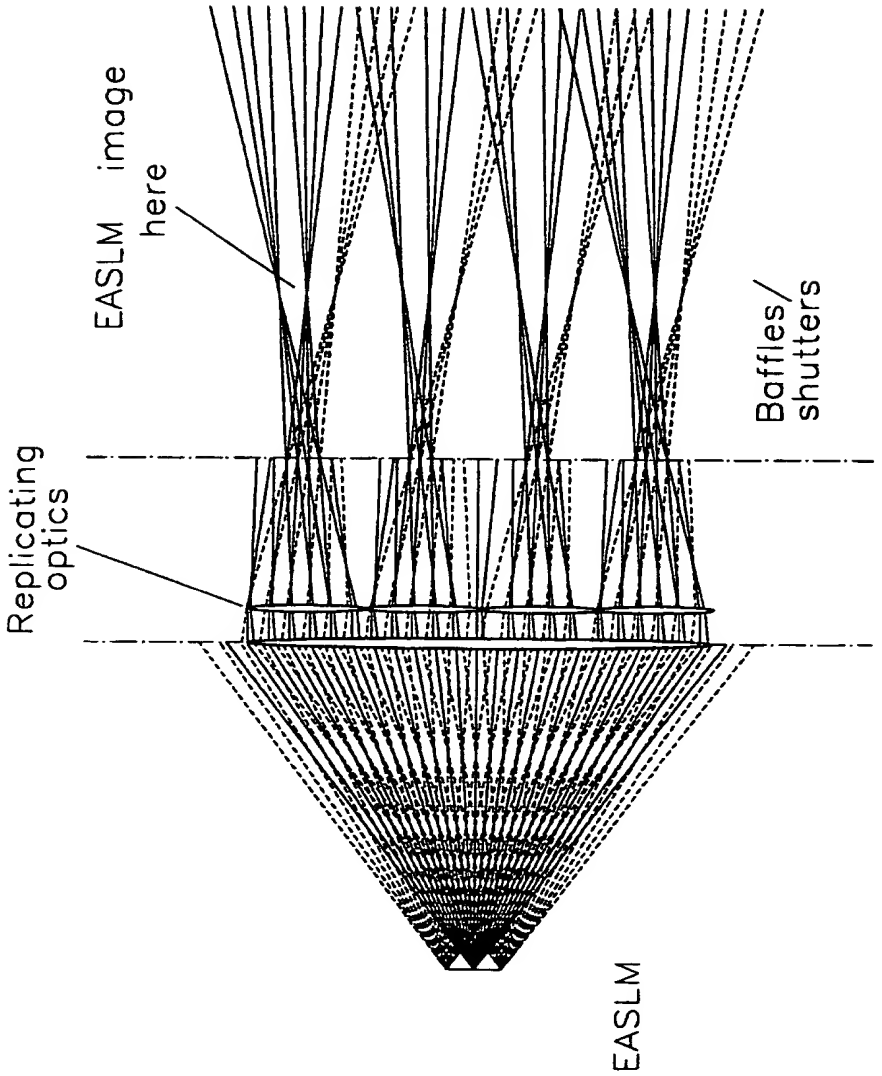

EASLM image here
Baffles/ shutters
Replicating optics
EASLM

FIG 2

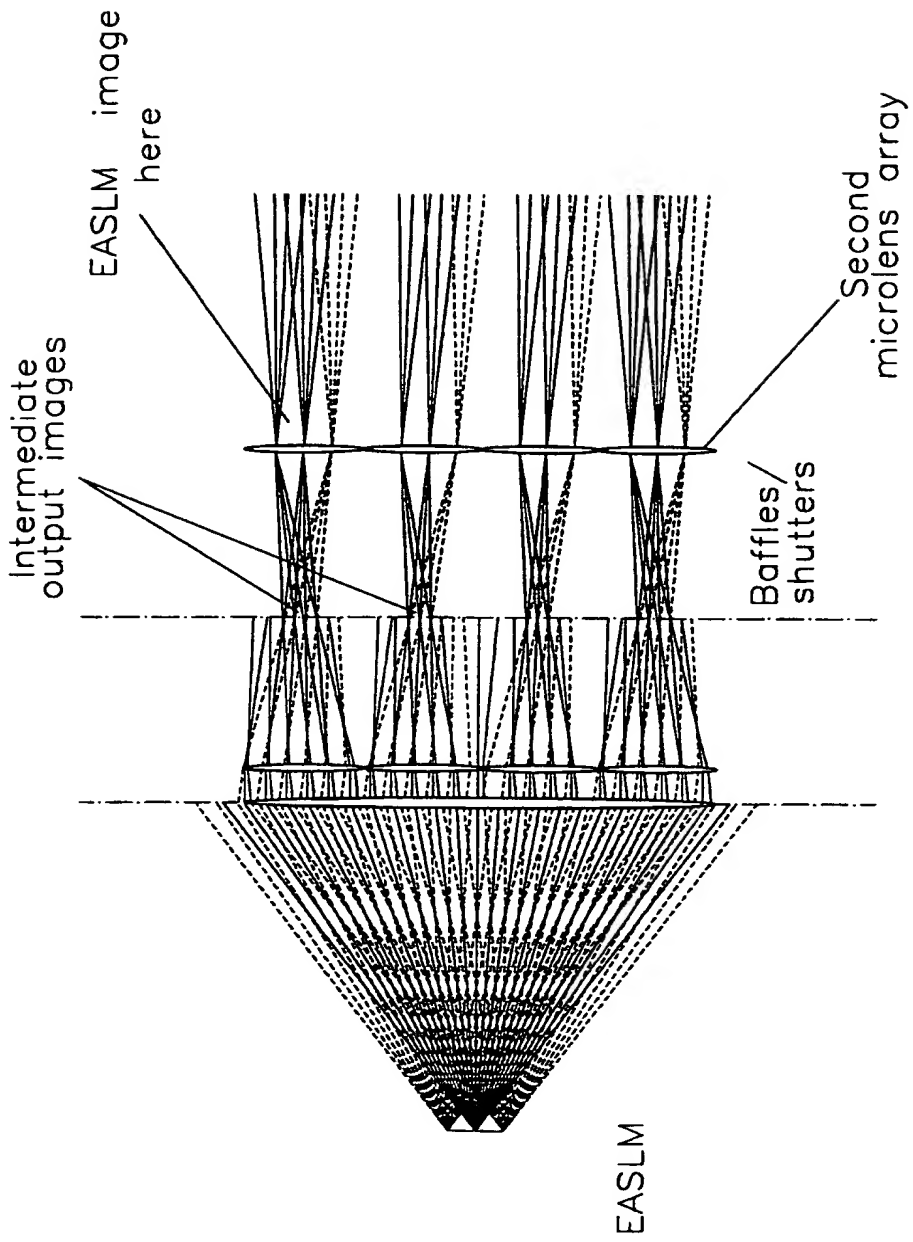

EASLM image here
Second microlens array
Intermediate output images
Baffles/ shutters
EASLM

FIG 3

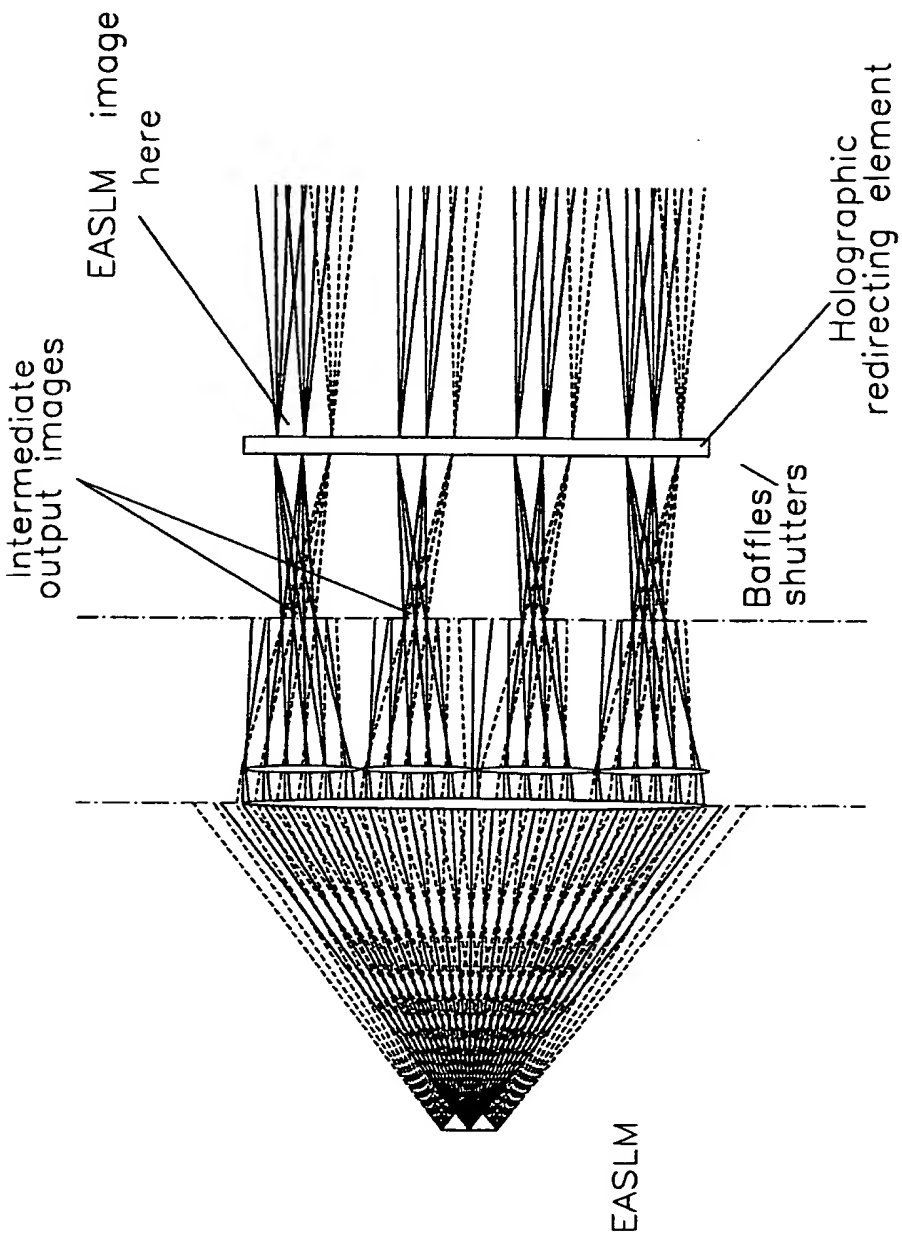

EASLM image here
Holographic redirecting element
Intermediate output images
Baffles/ shutters
EASLM

FIG 4

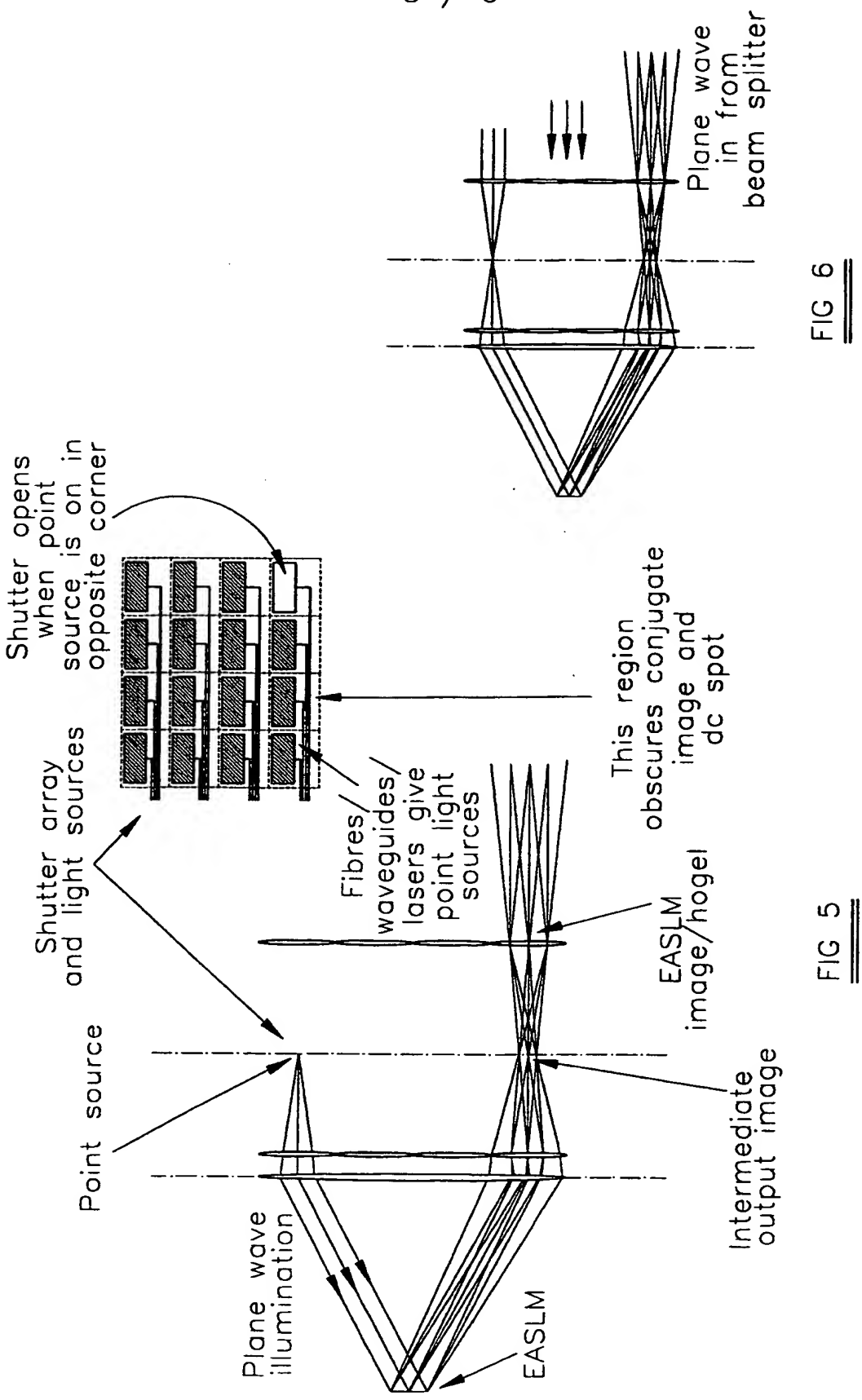

Plane wave in from beam splitter
Shutter opens when point source is on in opposite corner
Shutter array and light sources
Fibres/ waveguides/ lasers give point light sources
This region obscures conjugate image and dc spot
EASLM image/hogel
Point source
Intermediate output image
Plane wave illumination
EASLM

FIG 6

FIG 5

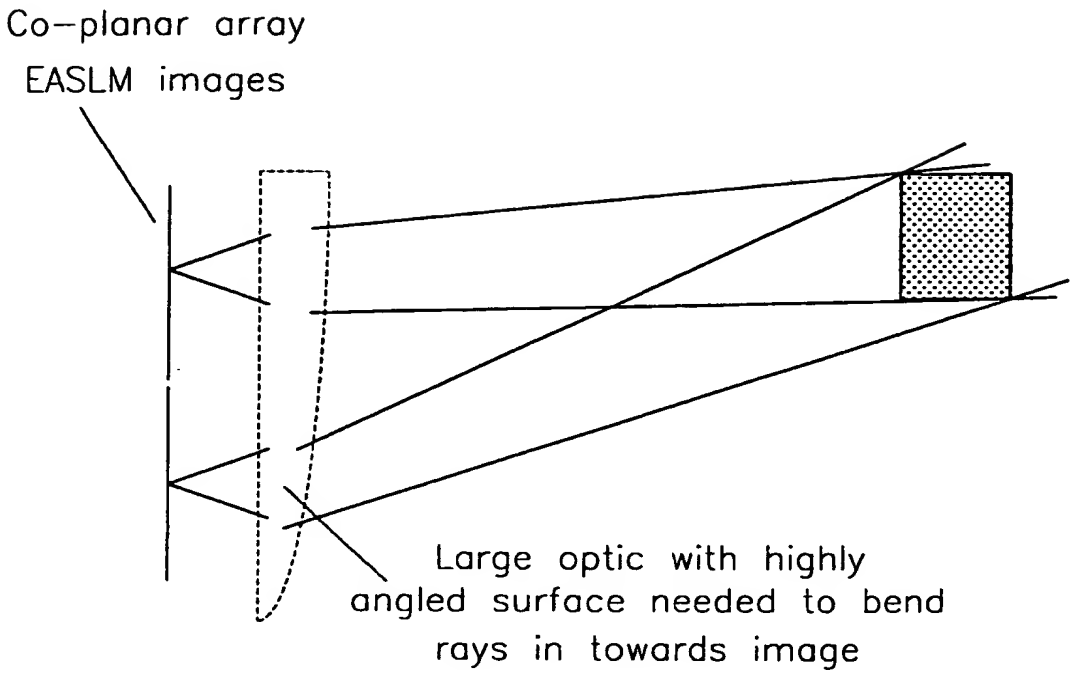

Co-planar array
EASLM images
Large optic with highly angled surface needed to bend rays in towards image

FIG 7

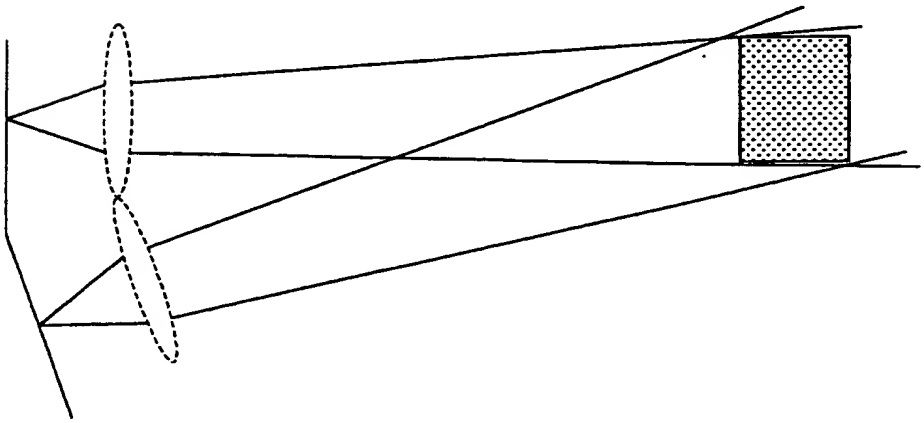


FIG 8

INTERNATIONAL SEARCH REPORT

Int. ational Application No
PCT/GB 00/01903

A. CLASSIFICATI N OF SUBJECT MATTER
IPC 7 G02B5/32 G03H1/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 652 666 A (RESTER DAVID H ET AL) 29 July 1997 (1997-07-29) column 2, line 38 - line 67 claim 1	1,2,6, 10,11
A	US 5 172 251 A (BENTON STEPHEN A ET AL) 15 December 1992 (1992-12-15) column 1, line 62 -column 3, line 12	1,10,11
A	US 5 138 471 A (MCGREW STEPHEN P) 11 August 1992 (1992-08-11) column 5, line 60 -column 6, line 66 figure 5	1,10,11

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 August 2000	28/08/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Krametz, E

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INTERNATIONAL SEARCH REPORT

Int. ..tional Application No
PCT/GB 00/01903

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 330 471 A (SECR DEFENCE) 21 April 1999 (1999-04-21) cited in the application page 2, paragraph 4 -page 4, paragraph 6 page 7, paragraph 4 -page 8, paragraph 1	1,3,10, 11

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/GB 00/01903

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		EP 1023631 A	02-08-2000
		WO 9919767 A	22-04-1999